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EFFECT OF WING TIP SHAPE ON VORTEX SHEET ROLLING UP

Robert Lengendre[1]

ABSTRACT. Laws of separation over a whole wing are applied to study of straight or moderately swept back wings. The effect of vortex sheet rolling up can be avoided by tailoring the profile of the trailing edge to the edge of a wing or blade, with constant or zero leading edge sweepback, in such a way as to make a clear distinction between the leading and trailing edges. Break phenomena are studied.

The laws of separation over the whole contour of a wing, discovered on /227* the occasion of studying delta wings, are applied to the study of straight or moderately swept back wings.

In 1950, ONERA (National Bureau for Aerospace Studies and Research) undertook the study of very slender wings, in a delta or swallowtail shape, with the specific goal of defining the conditions of utilization of such wings with large angles of attack for takeoff and landing of aircraft. The final result of the study was the design of a small experimental aircraft, the Deltaviex, by SNCASO (National Aeronautical Company of the Southwest), later merged into Sud-Aviation, then again merged into SNIAS (National Industrial Aerospace Company). The takeoff and landing tests of the Deltaviex, whose swallowtail shaped wing had a sweepback of 70° at the leading edge, confirmed that a very stable flight can be ensured at great angles of incidence and their results were quite useful in providing ONERA with the first project of the Concorde wing since it allowed selecting a sensible compromise between the qualities of cruising flight, where development of the vortex sheet is undesirable, and the study of a considerable high life available at low speeds by a wide extension of the vortex sheet.

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*Numbers in the margin indicate pagination in the foreign text.

From the beginning of the study, observation of the flow around delta wings, in hydraulic canal and wind tunnels, allowed discovery that the leading edge behaves like a conventional trailing edge at great angles of incidence and that it is the origin of a vortex sheet which is rolled up like a column and is connected continuously to the sheet coming out from the trailing edge.

This experimental observation was the origin of a new concept, generalizing that conceived by Prandtl which gained acceptance with great difficulty especially in France with the idea that the vortex sheet could only take its origin from the trailing edge was as solidly embedded as abroad.

The common sense idea that the fluid does not know this distinction, made by engineers, between trailing edge and leading edge of the wing and that any edge toward which it is directed in order to leave the obstacle is for it equivalent to a trailing edge, is universally accepted today. It is in no way in contradiction with the ideas of Joukowsky and Prandtl who had not considered the use of very slender wings. For lack of sufficient reading of French language publications, the origin of the new concept is often attributed incorrectly.

A fundamental law of the mechanics of fluids is applicable to all wings and it is advisable to revise and supplement, according to this law, the imaginative concepts of Prandtl.

As early as 1932, the author had observed in the hydraulic canal of the Carenes Testing Basin that the vortex sheets which make their escape from the blades of a model of a marine propeller do not take their origin with the maximum diameter but at a point of the leading edge as far proportionally upstream as the blade is wide and crushed at its tip. For lack of sufficient development of mathematical methods for study of flows, at this time, this experimental observation was not exploited. It is very clear today that the rolling up of vortex sheets downstream from a marine propeller has as its origin a break in the flow beginning from a point of the leading edge where a vortex flow is initiated taking a cone shape.

It is no longer necessary to repeat the same experiments in order to study the vortex sheets coming from a wing with a moderate sweepback or from a helicopter blade. The development of the use of computers allows in reality the forecasting of rolling up of the sheet around its edges, currently perfected for the potential flow of the fluid. Two attitudes are nevertheless possible: either to confine investigation to forecast this rolling up for conventional wing shapes, more or less improved by wing tips quite insufficient to avoid a break, or else to methodically study new shapes allowing better control of the formation of large wing tip vortices and their effects on the drag induced on the air fields located downstream, on the noise, on the vibrations, on the disturbance contributed in flight of aircraft passing through wakes.

It is very clear that, although the vortices of wing tips exist even now in a diagram, published by means of the new concept, of non-cyclical flow of a perfect fluid, they do not risk disappearing as an actual fluid. There are only some complications introduced by viscosity, such as the appearance of secondary vortices and naturally, with very great angles of incidence and in the case of wings with a moderate sweepback, the appearance of effects of separations on the upper wing surface. The attempts made before the war to interpret the formation of wing tip vortices by an instability of a sheet coming out just from the trailing edge appear today to have very little basis in fact since they do not take into account the powerful encouragement to rolling up constituted by the break at the wing extremity or on the leading edge.

As yet, there is no specific criterion for appearance of a break at the leading edge, but the mechanism is well understood and leads to the conclusion that no simple rule for this will ever be devised. The boundary layer separates when too abrupt a turn of the leading edge is imposed upon it and even now surely starting from the smallest deviations with respect to the adaptations, when the leading edge is quite thin. In the case of wings with a very pronounced sweepback intended for supersonic aircraft, the curve radius at the leading edge is always quite small and a connection sufficient for the conditions of flow at utilization, on one hand, and at large angles

of incidence, on the other hand, is obtained beginning from the simplifying hypothesis that the break at the leading edge appears starting with the slightest deviations from the incidence with respect to the one which was used as a basis for calculation of the camber and the twist. The same is not true for helicopter blades, straight wings, wings with a slight sweepback, since a cone shaped sheet of vortices cannot travel along the leading edge without being broken and carried off by the flow at the same time turning into multiple sheets coming from numerous centers of concentration on the wing upper surface providing a quite complicated appearance to the parietal flow observed.

The practical conclusion is that one should endeavor to not cause a break at the leading edge of wings with a moderate sweepback, still quite useful for subsonic aircraft, or at the leading edge of helicopter wings. A swift increase in the sweepback of the leading edge at the tip unavoidably sets up such a break which cannot even be useful with a significant high lift.

Nevertheless, it is not enough to avoid the break at the leading edge: a tip of a square wing, practically parallel to the wind, is no less unavoidably the origin of a sheet of cone shaped vortices as soon as the incidence appreciably increases. The use of a tip fairing can only slightly slow down /228
the appearance of the phenomenon at the same time, furthermore, making it less reliable.

The remedy is clear: it is necessary to run the profile of the trailing edge toward the tip of one wing or one blade, with constant or zero sweep-back of the leading edge in such a way as to make a clear distinction between the leading edge and the trailing edge, not only for the engineer over-occupied with geometry but for the fluid itself.

Investigations along these lines, undertaken at ONERA, have already supplied quite significant results. The use of high capacity modern computers allows carrying out calculations with perfect fluid which are excellent guides. It is possible to find shapes of the trailing edge such that the vortex sheet does not have a tendency to appreciably become run up around its

edges in a wide range of variation of incidence. Naturally, care should be taken, by wind tunnel testing, that the viscosity does not cause appearance of cases of rolling up into cones which no longer exist in the basic diagram. This care can not be satisfactory at high angles of incidence where massive separations appear along the upper surface of the wing. It is necessary to make sure, in addition, that the prolonged maintenance of a healthy flow with moderate angles of incidence does not introduce too great a discontinuity when it is no longer possible to avoid the appearance of a large scale separation.

The improvement of wing tips does not void arrangements made to make uniform the stalling characteristics. Although it is not desirable, in most of the applications of wings with a moderate sweepback, to cause an abrupt and generalized break at the leading edge, it can be quite useful to progressively start, by local actions, the gradual development of separation phenomena which cannot be avoided with very large angles of incidence.

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